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Simplified Equivalent Golden Finger Port Setup for Fast and Accurate High-Speed Channel Simulation

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***Abstract*— A simplified equivalent golden finger port setup is proposed for efficient, accurate 3D full-wave simulation for high-speed channels. The bent connector pins, which mate with the golden finger, are simplified as equivalent cylindrical pins to meet the wave port setting requirements for 3D full-wave simulation. The effects of the equivalent cylindrical pin location and diameter are analyzed through 3D full-wave simulation. A closed-form expression is newly proposed to correlate the location and diameter of the equivalent cylindrical pin with respect to the widely used bent connector pin. On the basis of the closed-form expression, the bent connector pin can be accurately replaced by the simplified equivalent cylindrical pin structure in 3D full-wave simulation. Practical examples using commercial high-speed connector pin models with gold fingers verify that the proposed modeling method is accurate and efficient up to 40 GHz.**

Keywords—Golden finger, equivalent cylindrical, bent connector, closed-form expression.

I. INTRODUCTION

High-speed channel design and optimization of printed circuit boards (PCBs) have become more challenging as the physical dimension of high-speed digital systems has scaled down with increased data rates [1], [2]. To evaluate and ensure the signal integrity of high-speed channels before fabrication, accurate and time-efficient 3D full-wave simulation for high-speed connectors with golden finger structures is critical. Accurate and fast simulation requires proper modeling of the interconnections between components, including the interfaces between the PCB and the integrated circuits (ICs). Golden fingers, which are used to connect PCBs and ICs through a series of metal fingers, are commonly used for the interconnection of high-speed channels [3], [5]. As shown in Figure 1, serial golden fingers are present on the PCIe board. However, setting up golden finger ports for 3D full-wave simulation can be challenging, because of the complex geometry and the need for precise parameterization [4]. In addition, the wave ports in 3D full-wave simulation for accurate simulation of the high-speed channel cannot be attached directly to gold fingers, because of their geometrical shape [5].

Herein, we present a practical and simplified equivalent model for golden finger port setup to achieve efficient and accurate high-speed channel simulation results. The equivalent cylindrical pins are proposed to replace the actual bent pins of the high-speed connector for the golden finger interconnection, to enable convenient port setup. Through the use of simplified equivalent cylindrical pins, the high-speed channel with the mated golden fingers can meet the wave port setting requirements for 3D full-wave simulation. The effects of the simplified equivalent cylindrical pin location and diameter are analyzed through 3D full-wave simulations herein. On the basis of the analysis, a closed-form expression is proposed to correlate the locations and the diameters of the simplified equivalent cylindrical pin with those of the bent connector pin. With the closed-form expression, the bent connector pins can be accurately replaced by the proposed equivalent cylindrical pins in 3D full-wave simulation. The simulation results of the high-speed channel with the equivalent cylindrical pins can accurately and efficiently calculate the electrical performance with actual bent pins without requiring an additional step for

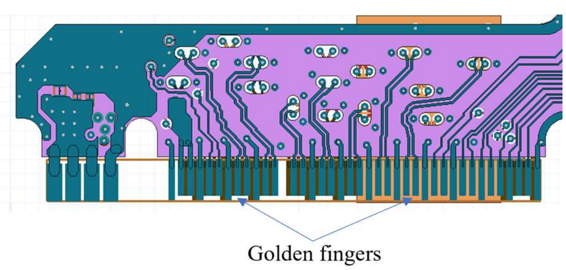
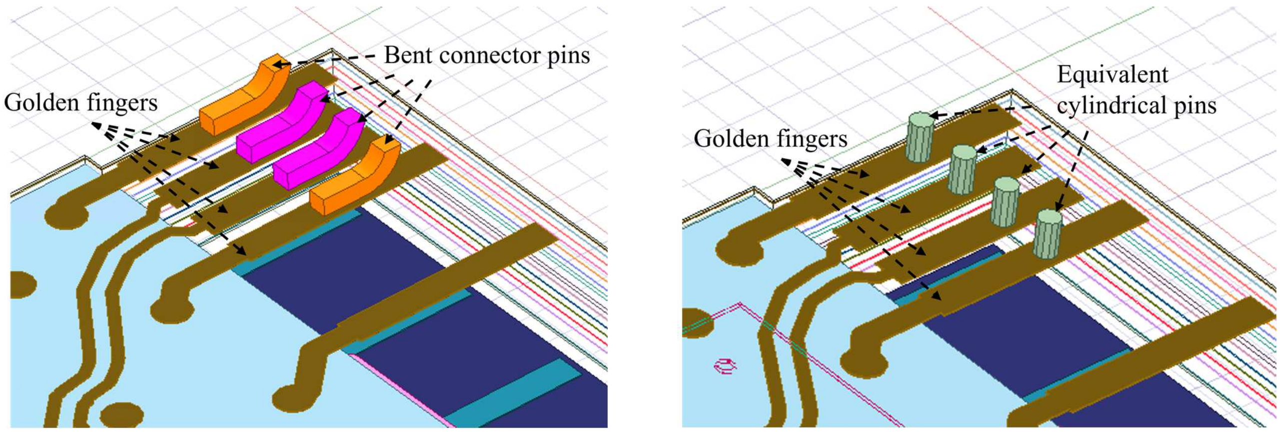


Fig. 1. Top view of a part of a PCIe board with golden fingers.



(a) (b)

Fig. 2. 3D model of a high-speed channel with golden fingers and mated connector pins from the PCIe board shown in Figure 1: (a) with bent connector pins, (b) with simplified equivalent cylindrical pins.

setting a wave port. Practical examples using commercial high-speed connectors with bent pins verify that the proposed modeling method is accurate and efficient up to 40 GHz.

II. The Proposed Modeling Method

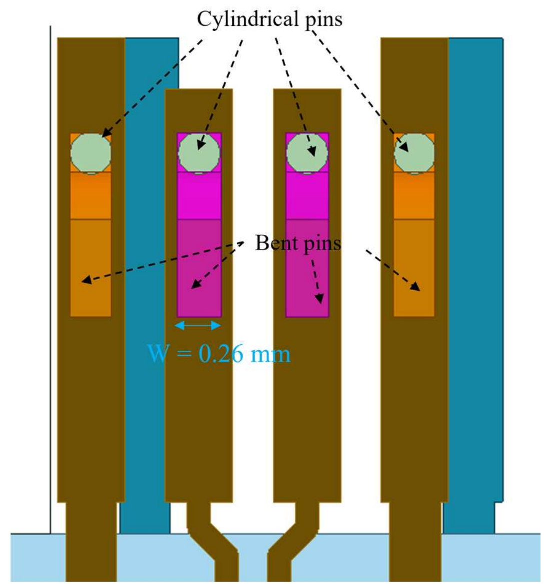
In this section, the simplified equivalent model for the bent pins of the connector is introduced. A closed-form expression is newly proposed to correlate the location and the diameter of the equivalent cylindrical pin with those of the bent connector pin on the golden finger. On the basis of the 3D full-wave simulation, the effects of the equivalent cylindrical pin location and diameter are analyzed.

A. Proposed Simplifed Equivalent Cylindrical Pin

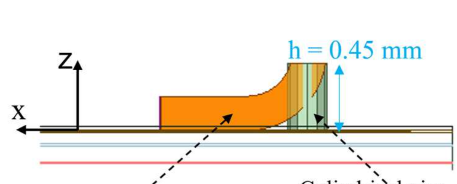
Owing to the complex geometrical shape of the bent pins that mate with the golden finger, as shown in Figure 1, the wave port cannot be attached directly to the mated golden finger and pin pair for accurate and time-efficient 3D full-wave simulation. For application of the wave port in the simulation, the cylindrical pin, which resembles a solder ball, is often added on top of the golden finger pad to replace the bent pin [6]. The diameter and the location of the cylindrical pin must be determined for accurate simulation of high-speed channels. In practice, bent connector pins, as shown in Figure 1 (a), are used for the connection of golden fingers between the motherboard and the daughter card. Herein, a simplified cylindrical pin, as shown in Figure 1 (b), is used to replace the bent connector pin for efficient simulation. By using simplified cylindrical pins, the wave port in 3D full-wave simulation can be directly applied in the channel simulation, thus supporting accurate simulation results.

B. Effects of Simplified Equivalent Pin Location and Diameter

The height, h, of the equivalent cylindrical pin is assumed to be same as the height of the bent connector pin. Meanwhile, the diameter D of the equivalent cylindrical pin is assumed to be the same as the width, W, of the bent connector pin. The relative location of the equivalent cylindrical pin with respect to the location of the bent pin is shown in Figure 3, in which the cylindrical pin and the bent pin are plotted together. The effects of the equivalent cylindrical pin diameter and location are investigated by sweeping the diameter and location parameters according to the full-wave simulation.



(a)



(b)

Fig. 3. The initial relative location of the equivalent cylindrical pin with respect to the location of the bent pin: (a) top view, (b) side view.

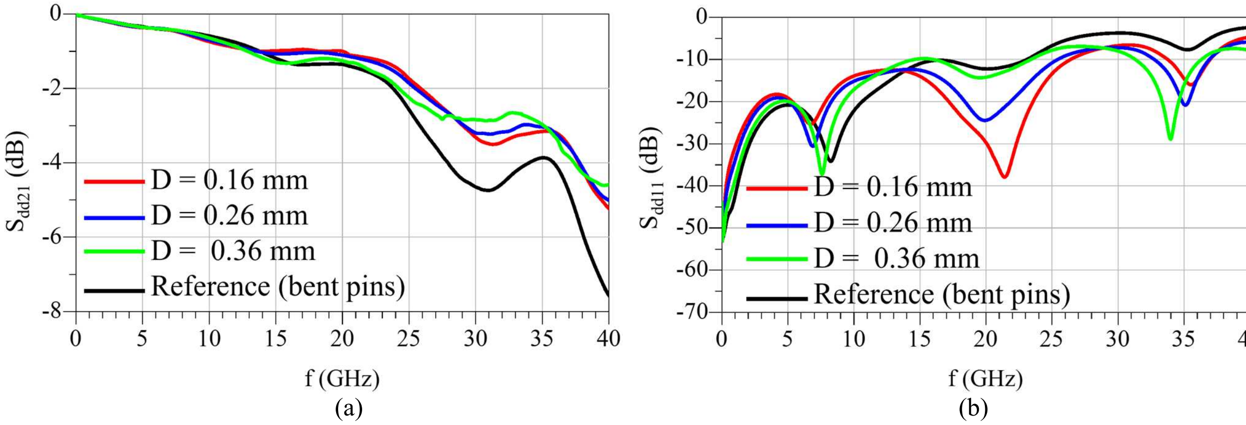


Fig. 4. S-parameters comparison of the high-speed channel with different pins with various pin diameters: (a) Differential insertion loss comparison, (b) Differential return loss comparison.

Figure 4 shows the S-parameter comparison of the high-speed channel with different pins, in which the diameter of the equivalent cylindrical pin is swept from 0.16 mm to 0.36 mm, with a 10 mm step size. The red, blue, and green curves correspond to the simulation results for a high-speed channel with the proposed cylindrical pins having different diameters. The black curve represents the results of the high-speed channel with the real bent connector pins. To obtain simulation results for the channel with bent connector pins, an extra transmission line model was added on top of the bent connector for the wave port setup, which was finally de-embedded for channel result comparison. However, the wave port could be directly attached to the cylindrical pin through use of a ground sheet. According to the comparison, the cylindrical pin diameter has a negligible effect on the differential insertion loss of the channel; however, it has a relatively large effect on the differential return loss of the channel, because of the difference in channel impedance due to the different pin diameters. The results for the high-speed channel with the proposed cylindrical pins do not match those for the channel with the actual bent pins, thus indicating that the location of the proposed pins must be modified.

Figure 5 shows the S-parameter comparison of the high-speed channel with different pins, wherein the location of the equivalent cylindrical pins is shifted in the positive *x*-direction. A relatively small location shift of the cylindrical pins can significantly change the differential insertion loss and return loss. As the pin location shifts, the channel length and the channel impedance change significantly, while the stub length of the golden finger is increased. Therefore, the proposed simplified cylindrical pins' locations must be carefully defined. Through comparison of different simulation results at different cylindrical pin locations, the channel with the equivalent pins is seen to match well with the results of the channel with the actual bent pins when the equivalent pins are shifted by 0.4 mm in the positive *x*-direction.

C. Correlation between Equivalent and Bent Pins

The correlation between the proposed equivalent cylindrical pin and the bent connector pin can be characterized by the closed-form expression shown below:

$$D = W \tag{1}$$

$$H_c = H_b \tag{2}$$

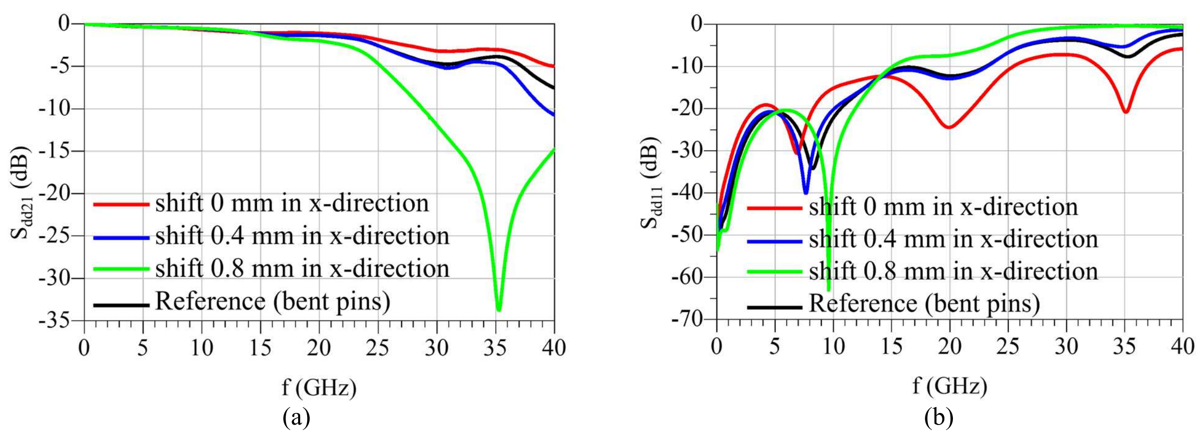
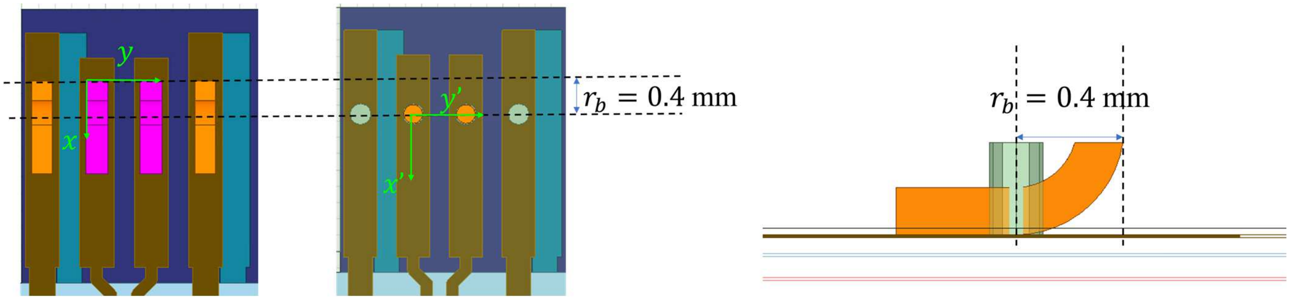


Fig. 5. S-parameters comparison of the high-speed channel with different pins with various pin locations: (a) Differential insertion loss comparison, (b) Differential return loss comparison.



(a) (b)

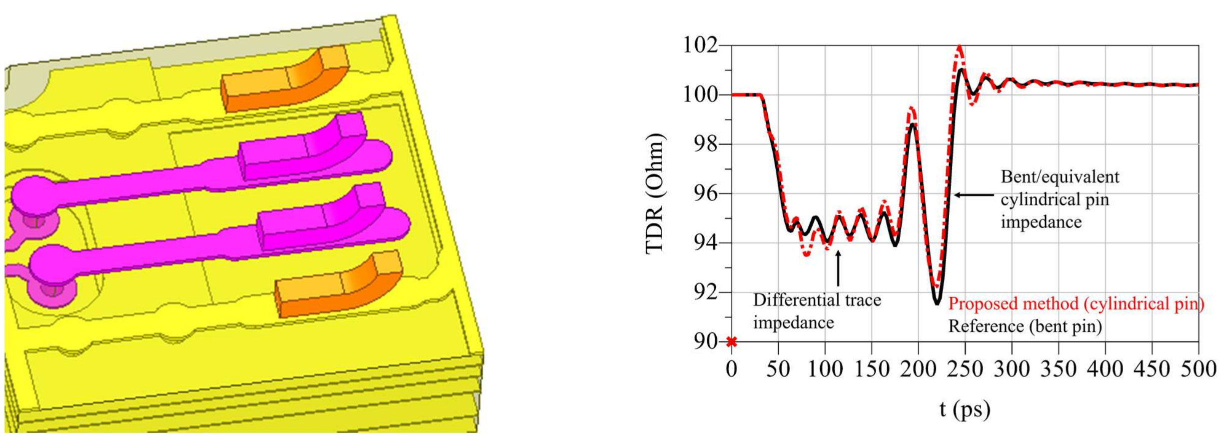
Fig. 6. Location characterization of the proposed equivalent cylindrical pins based on the location of the actual bent connector pins: (a) top view, (b) side view.

$$x' = x + \frac{D}{2},\ \ y' = y + r_b \tag{3}$$

where D and W are the diameter of the equivalent cylindrical pin and the width of the bent pin, respectively, and H_c and H_b are the height of the equivalent cylindrical pin and the height of the actual bent pin, respectively. The location of the proposed equivalent cylindrical pin is characterized by its coordinates according to the coordinates of the real bent pin. The relative locations of the equivalent cylindrical pins and the actual bent pins are shown in Figure 6. Two coordinates are provided to correlate the location relationship between the real bent connector pin and the equivalent cylindrical pin: x and y are the coordinates of one signal pin for the real bent connector pin, whereas x' and y' are the coordinates of the equivalent cylindrical pin for the same signal. Thus, x' and y' are calculated from x and y with equation (3). r_b is the relative distance between the equivalent cylindrical pins and the actual bent pins, which is 0.4 mm in the x-direction in this case. Figure 6(b) shows the relative locations of the equivalent cylindrical pins and the actual bent pins when $r_b = 0.4$ mm. The desired shift in the x-direction is equal to the radius of the bent part of the connector pin. This correlation is observed because the location shift of the simplified equivalent cylindrical pins must match where the electrical signal propagates into the golden finger. In other words, the position of the equivalent model is determined by the stub length of the golden finger. Finally, the equivalent cylindrical pin for a wave port setup can be modeled in 3D simulation based on the proposed expression. In practice, the physical size and location of the actual bent connector pin can be provided by the connector pin vendor.

III. Model Verification

The proposed modeling method is verified by a different connector model, as shown in Figure 7 (a). The height and the width of the bent pin are 0.65 mm and 0.32 mm, respectively. Another commercial bent connector pin is modeled by the proposed cylindrical pin according to the proposed closed expression. To verify the accuracy and efficiency of the proposed method, the S-parameter comparisons of the high-speed channel are plotted in Figure 8, wherein the black curve indicates the simulation results of the channel with bent pins, and the red curve indicates the simulation results of the channel with cylindrical pins. Both the differential insertion loss and differential return loss of the high-speed channel can be accurately modeled with the proposed method up to 40 GHz.



(a) (b)

Fig. 7. A different 3D mated connector model with the golden fingers and the bent pins. The height and the width of the bend pin is different with the model in Figure 3. (a) 3D view, (b) Differential mode TDR of the connector model (rise time is 30 ps).

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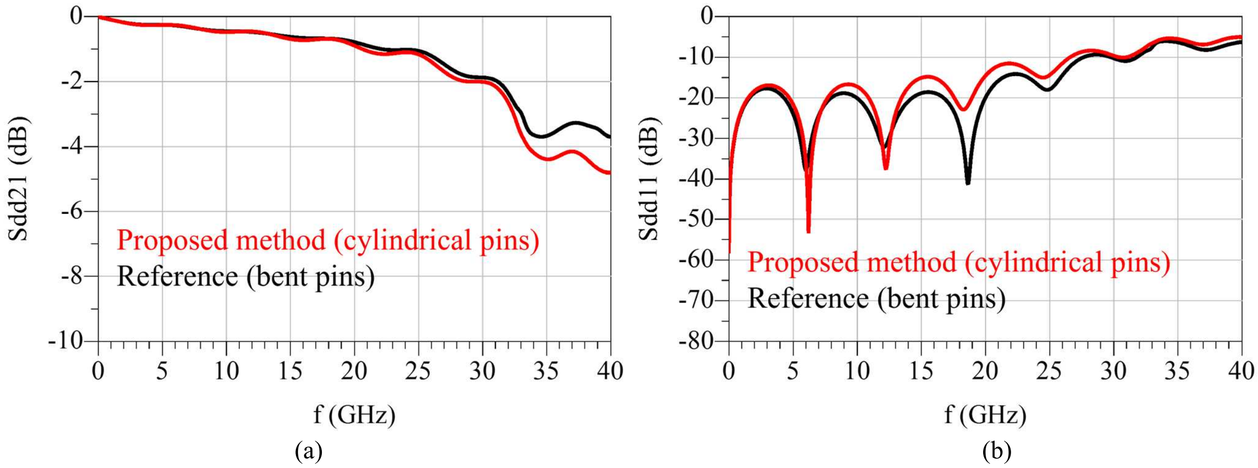

Fig. 8. Location characterization of the proposed equivalent cylindrical pins based on the location of the actual bent connector pins: (a) top view, (b) side view.

The resonance frequency of the channel also shows high correlation. To further verify the proposed model, a comparison of differential mode time domain reflection (TDR) between the initial bent pin model and the equivalent cylindrical pin model is plotted in Figure 7 (b). The TDR impedance of the initial model can also be accurately predicted with the proposed method. Using simplified equivalent cylindrical pins rather than bent pins can therefore save simulation time without requiring an additional step for setting a wave port.

IV. Conclusion

Herein, we presented a simplified cylindrical pin model for a golden finger port setup to achieve accurate and efficient simulation results for high-speed channels with mated golden finger and pin pairs. The bent pins of the high-speed connector of the mated golden finger and pin pair are replaced by simplified equivalent cylindrical pins to meet the wave port setting requirements for 3D full-wave simulation at the location and cylinder radius defined by the proposed closed form equation. The effects of the equivalent cylindrical pin location and diameter were analyzed with 3D simulations. The simplified equivalent cylindrical pin diameter and location both affect the differential insertion loss and return loss response of the simulation results for the high-speed channel. On the basis of this analysis, a closed-form expression is proposed to correlate the location and diameter of the simplified equivalent cylindrical pin to replace the bent connector pin. The locations of the proposed equivalent cylindrical pins are defined according to the location where the signal propagates into the golden finger from the bent connector pins, because the stub length of the golden finger greatly influences the resonance of the signal channel. The proposed method can help high speed channel designers efficiently simulate high-speed channel applications with golden finger ports.

V. Acknolwedgements

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References

[1] S. H. Hall, G. W. Hall, and J. A. McCall, *High-Speed Digital System Design—A Handbook Of Interconnect Theory and Design Practices*. New York, Wiley, 2000, ch. 5, pp. 94–116.

[2] B. Pu, J. He, A. Harmon, Y. Guo, Y. Liu and Q. Cai, "Signal Integrity Design Methodology for Package in Co-packaged Optics Based on Figure of Merit as Channel Operating Margin," *2021 IEEE International Joint EMC/SI/PI and EMC Europe Symposium*, 2021, pp. 492-497, doi: 10.1109/EMC/SI/PI/EMCEurope52599.2021.9559168.

[3] W. Clark, "The PCB Connector as a Surface Mounted Device," in *IEEE Trans actions on Components, Hybrids, and Manufacturing Technology*, vol. 8, no. 4, pp. 530-534, December 1985, doi: 10.1109/TCHMT.1985.1136522.

[4] C. -H. Chen, C. -H. Chen, C. -L. Liao and B. Mutnury, "Impact of SMT Connector Pads on High Speed Serial Links," 2018 IEEE Electrical Design of Advanced Packaging and Systems Symposium (EDAPS), Chandigarh, India, 2018, pp. 1-3, doi: 10.1109/EDAPS.2018.8680854.

[5] H. Ju et al., "Printed Circuit Board (PCB) Routing optimization with an Innovative Edge Connector for PCI-Express 5.0 and Beyond," 2022 17th International Microsystems, Packaging, Assembly and Circuits Technology Conference (IMPACT), Taipei, Taiwan, 2022, pp. 1-4, doi: 10.1109/IMPACT56280.2022.9966709.

[6] V. Issakov et al., "Co-simulation and co-design of chip-package-board interfaces in highly-integrated RF systems," 2016 IEEE Bipolar/BiCMOS Circuits and Technology Meeting (BCTM), New Brunswick, NJ, USA, 2016, pp. 94-101, doi: 10.1109/BCTM.2016.7738959.